Experiments with stable confined Electron Columns

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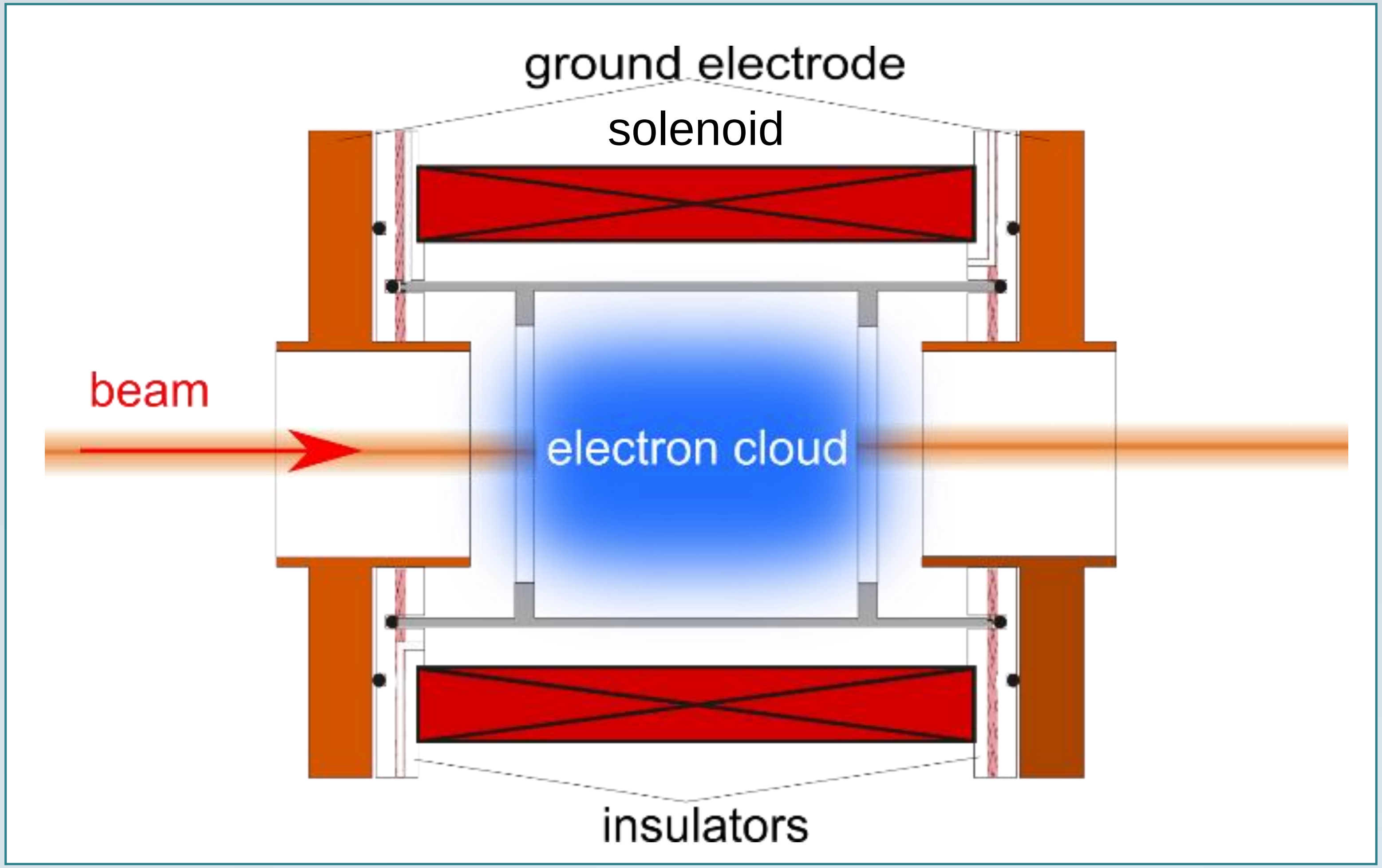
Gabor Lens– basic principle



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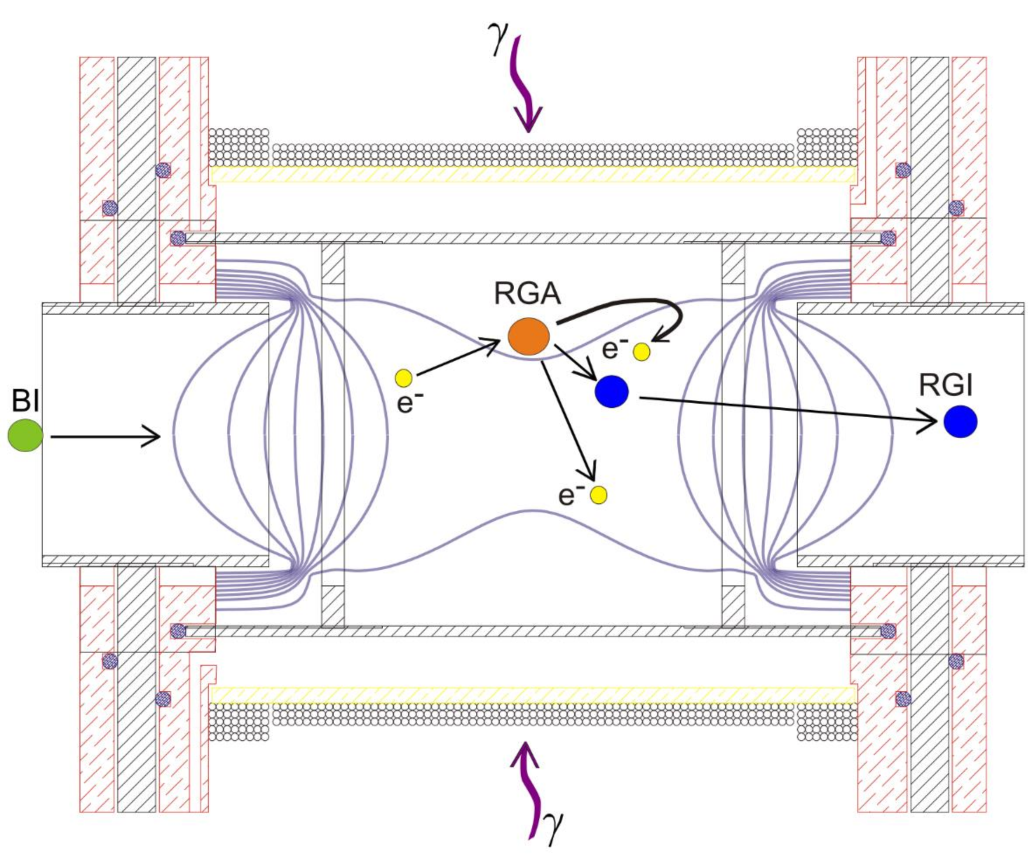
Why - Experiments with stable confined Electron Columns?

- Studying plasma
  - Plasma parameter (density, temperature)
- Studying interactions between column and ion beam
  - Focal strength
  - Charge exchange / recombination
- Focussing high intensity ion beams
  - Space-charge compensation

Gabor Lens– basic principle



<u>Electron production</u>

- No external emitters
- Cosmic radiation, residual gas excitation

➢Avalanche effect

BI + RGA -> BI + RGI + e^-

γ + RGA -> RGI + e^- + γ‘

e^- + RGA -> RGI + 2e^-

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Gabor Lens– basic principle

Determining the plasma state:

- Debye Length: λ_D

$$\lambda_D^2 = \frac{\varepsilon_0 k_B T_e}{n_e e^2}$$

with T_e = 100 eV, $n_e = 1 \cdot 10^{14}\ m^{-3}$
$\rightarrow \lambda_D$ = 7.4 mm

- Plasma Frequency: ω_{pe}

$$\omega_{pe} = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$

with $n_e = 1 \cdot 10^{14}\ m^{-3}$
$\rightarrow \omega_{PE}$ = 564 MHz

Gabor Lens– basic principle

Determining the plasma state:

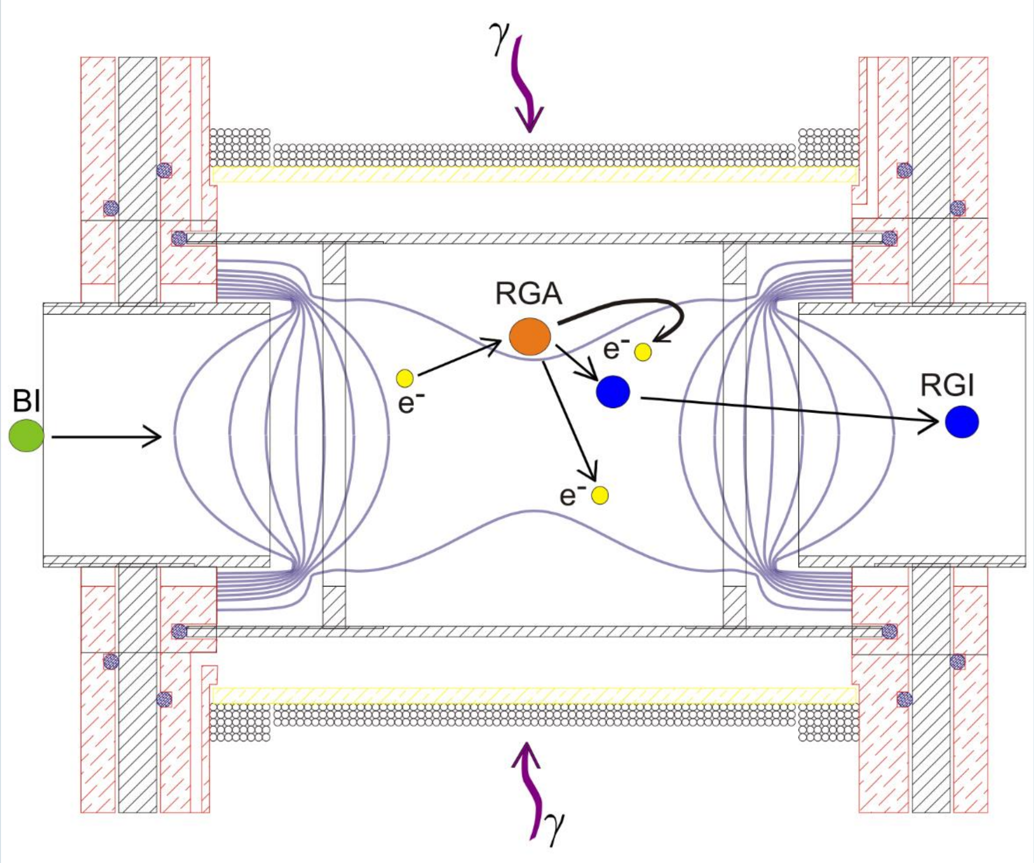
$L/\lambda_D >> 1$

$\omega_{pe} \cdot \tau >> 1$

$N_D = \frac{4}{3}\pi\lambda_D^3 >> 1$

- Non-neutral plasma, only one particle species

Gabor Lens– basic principle



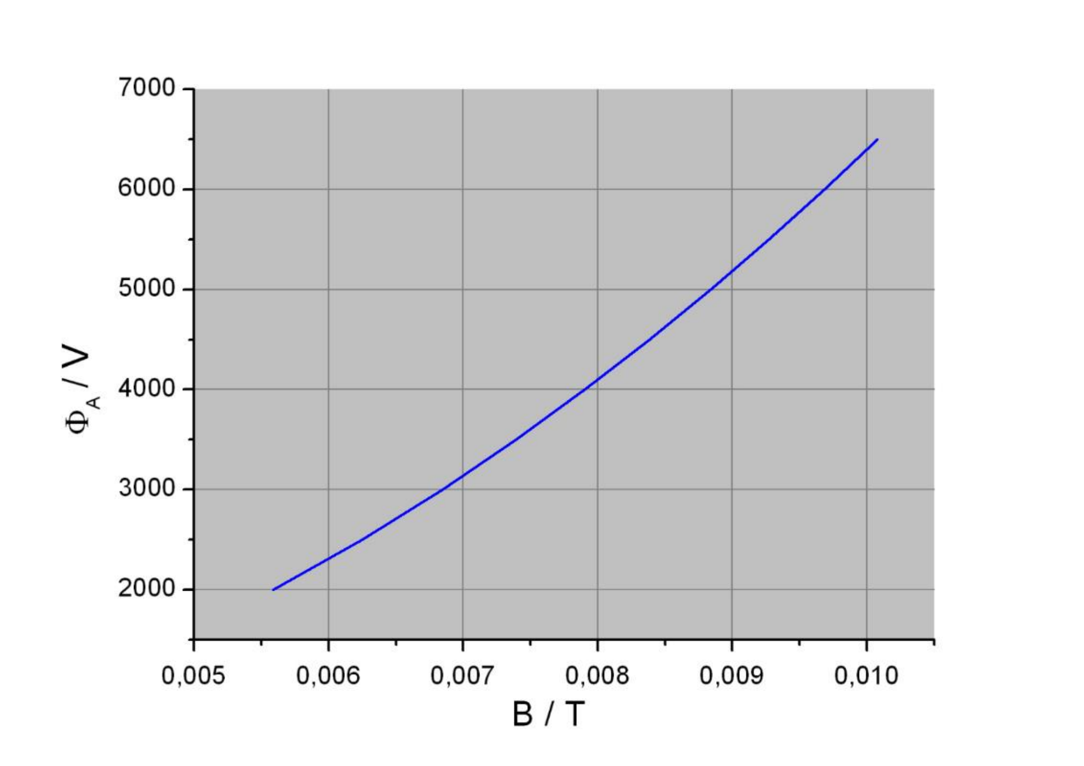
Radial confinement: axial symmetric magnetic field

$$n_e = \frac{\varepsilon_0 B z^2}{2 m_e}$$

Longitudinal confinement: potential barrier

$$n_e = \frac{4 \varepsilon_0 \phi_A}{e r^2}$$

Gabor Lens– basic principle



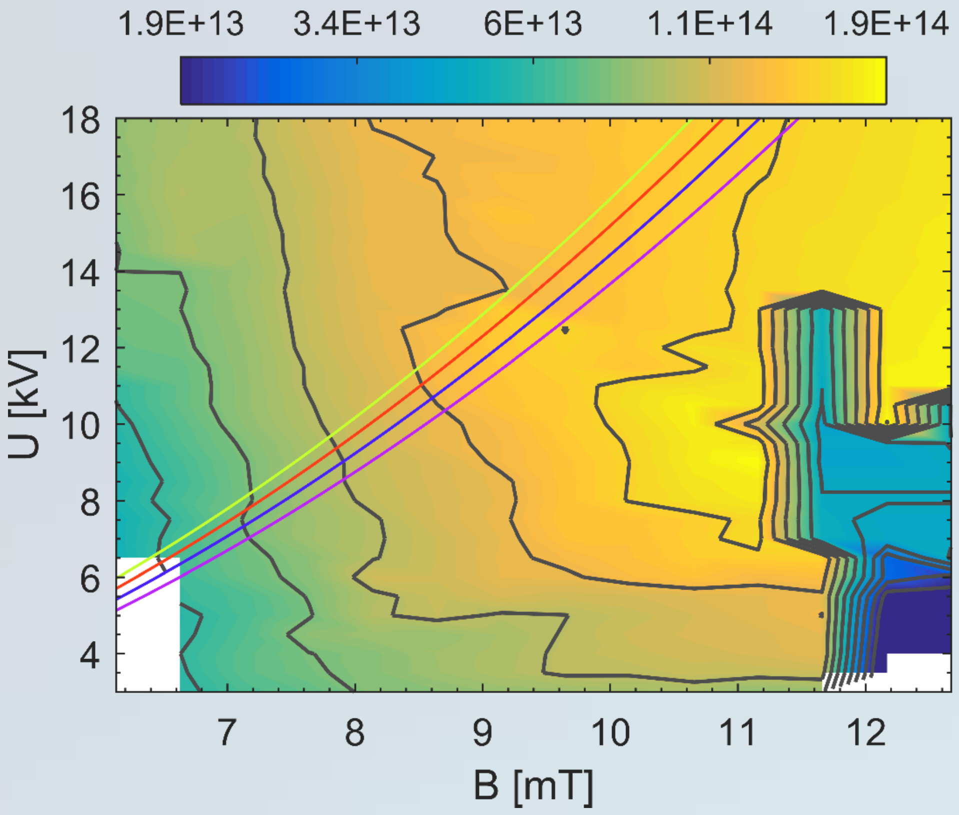
$$n_{e,max,radial} = n_{e,max,long}$$

$$\phi_A = \frac{B_Z^2 e r^2}{8 m_e}$$

$\Rightarrow$operation function

- The confinement properties of the Gabor Lens depend on the parameters: potential, magnetic field and pressure

Gabor Lens– basic principle

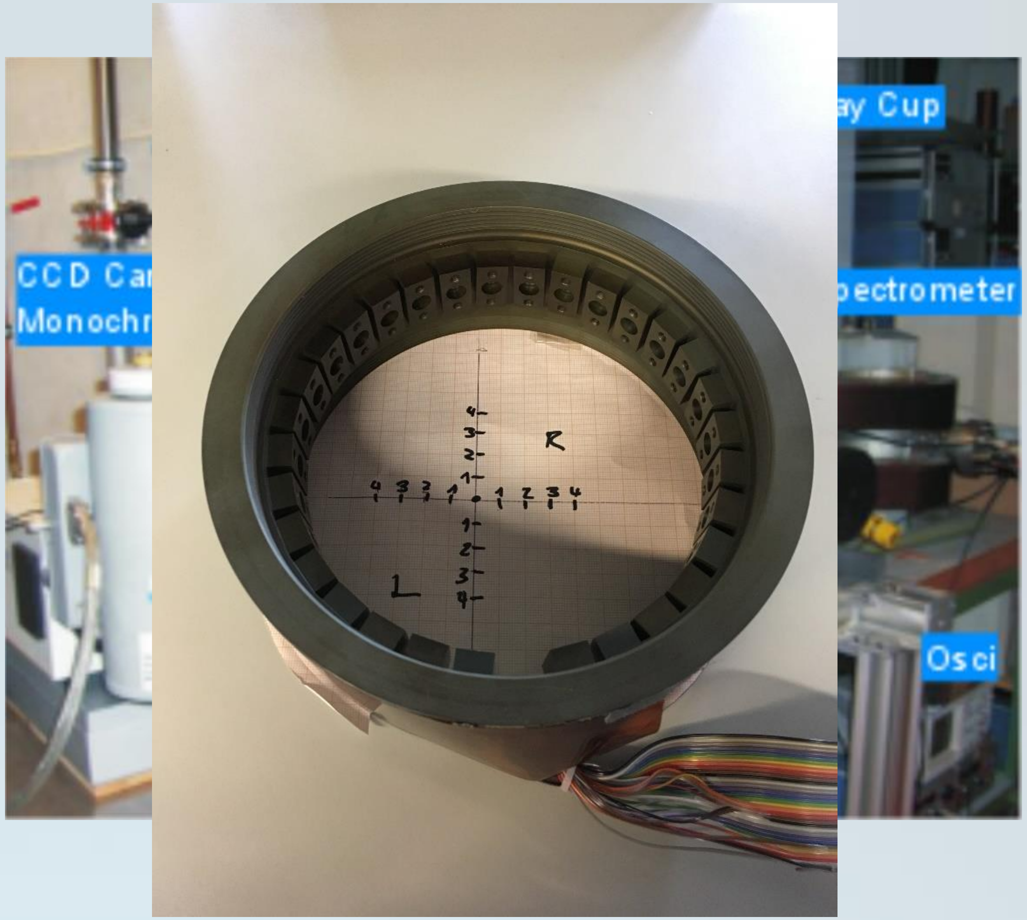


- Confinement of the electrons exists even if you are not on the operation function

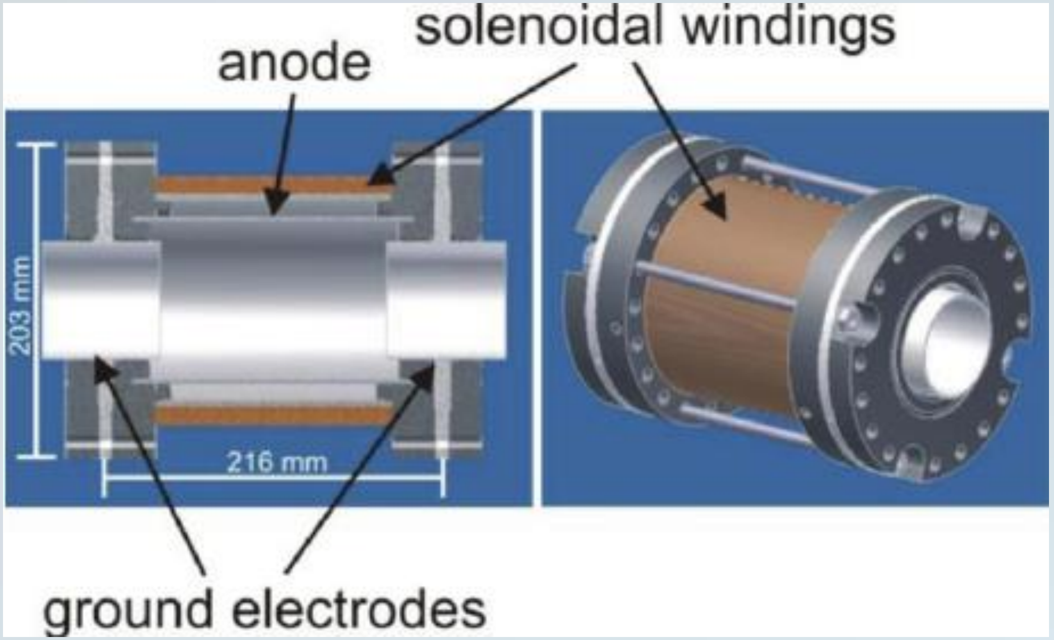
➢ Operation function shows optimal imaging properties for beam focussing

Diagnostic Analysis

- Emittance measuring system
- Faraday Cup
- CCD Cam
- Monochromator
- Momentum spectrometer
- Insitu diagnostics (Diode ring)
- Control system



1. Small Single-Segment Gabor Lens

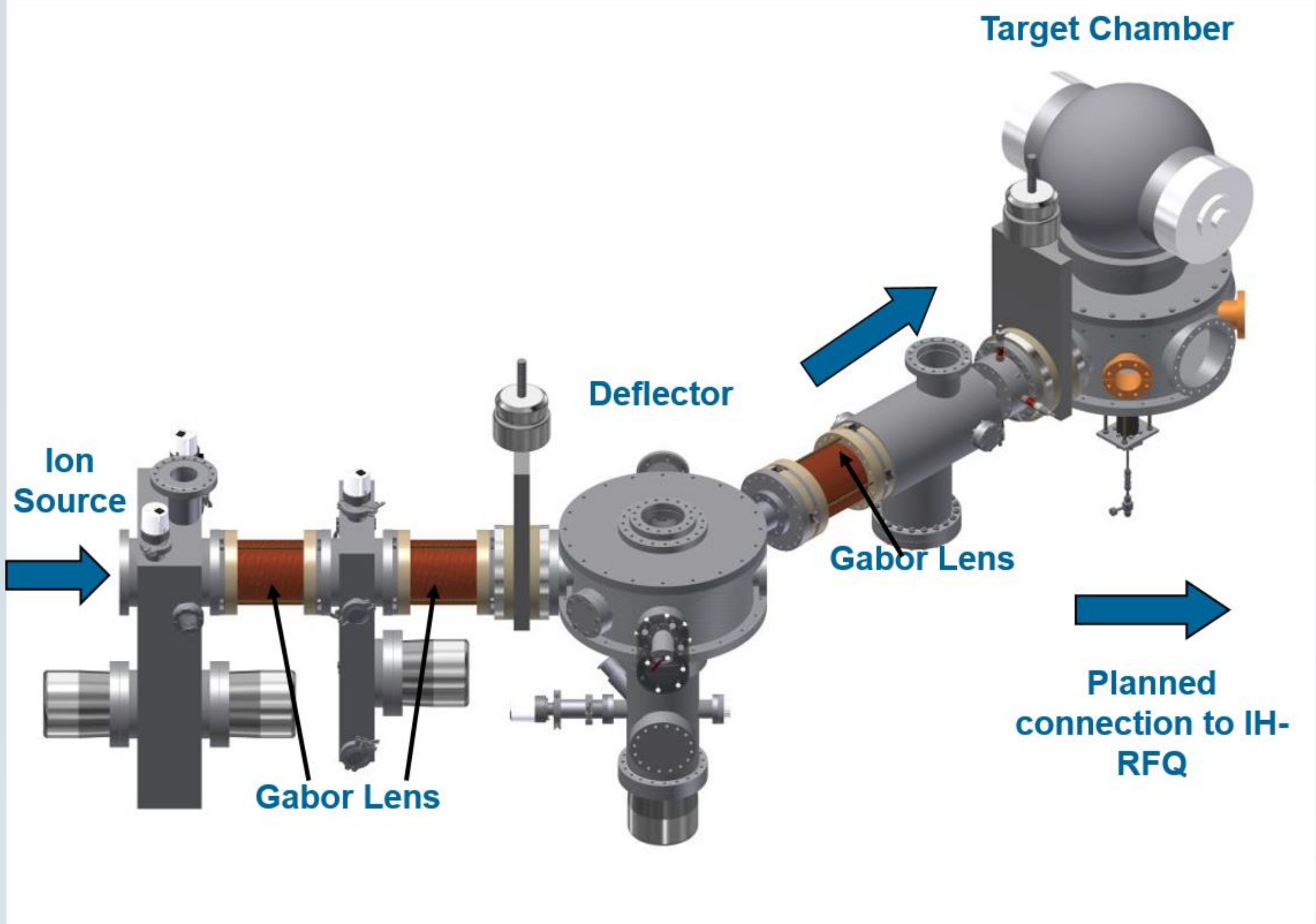


- r/l: 0.035/0.216 = 0.16
- $\phi_{A,max}$ ≈ 6 kV
- B_{max} ≈ 30 mT

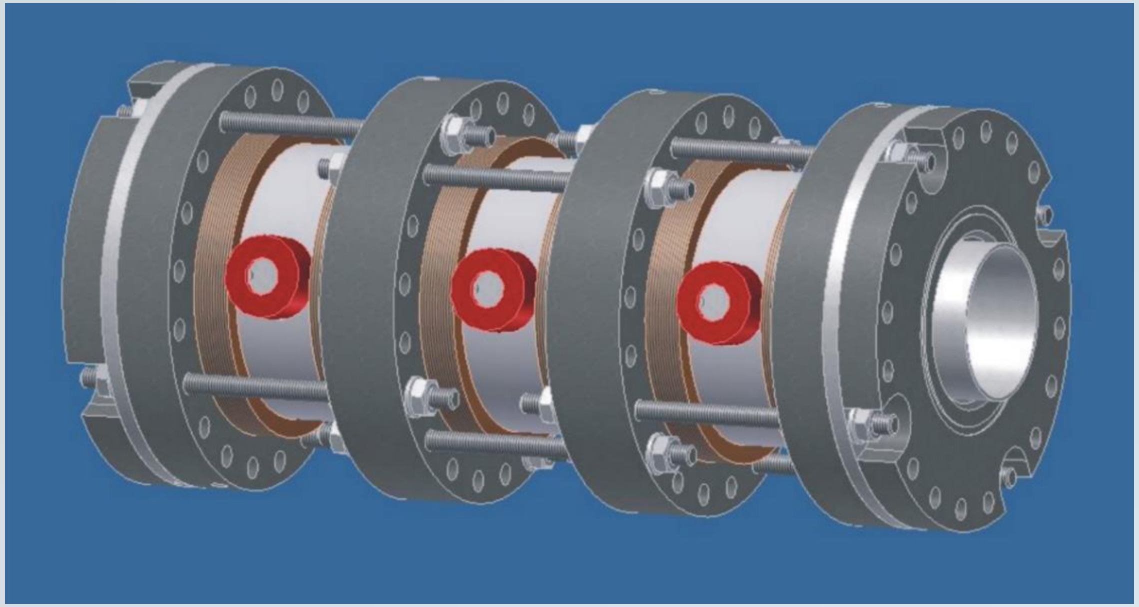
<u>Research topics:</u>

- Effective focussing (Ar- and He-beam 30 keV)
- Space-charge compensation

1. Small Single-Segment Gabor Lens



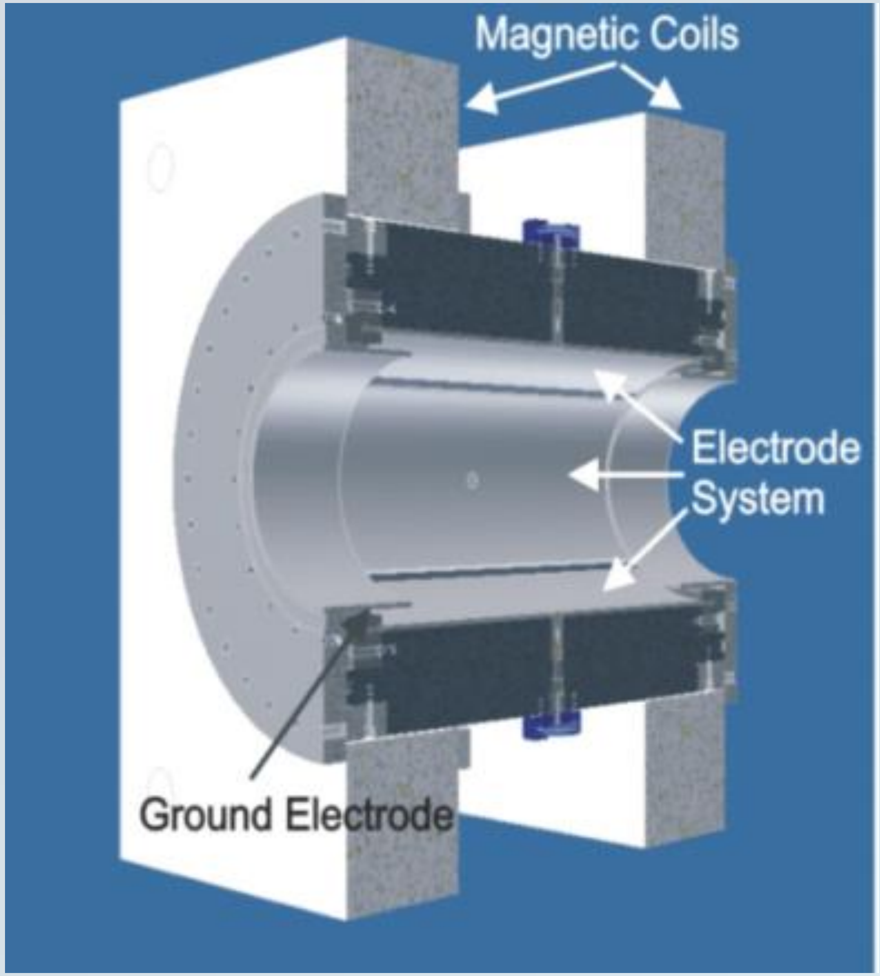
3-Segmented Gabor Lens



- r/l: 0.035/0.4 = 0.087
- Inspection windows - optic diagnostic is possible

- Segmentation - Longitudinal gradient for magnetic field and potential
- Development of new diagnostic concepts

Hero – Segmented Gabor Lens

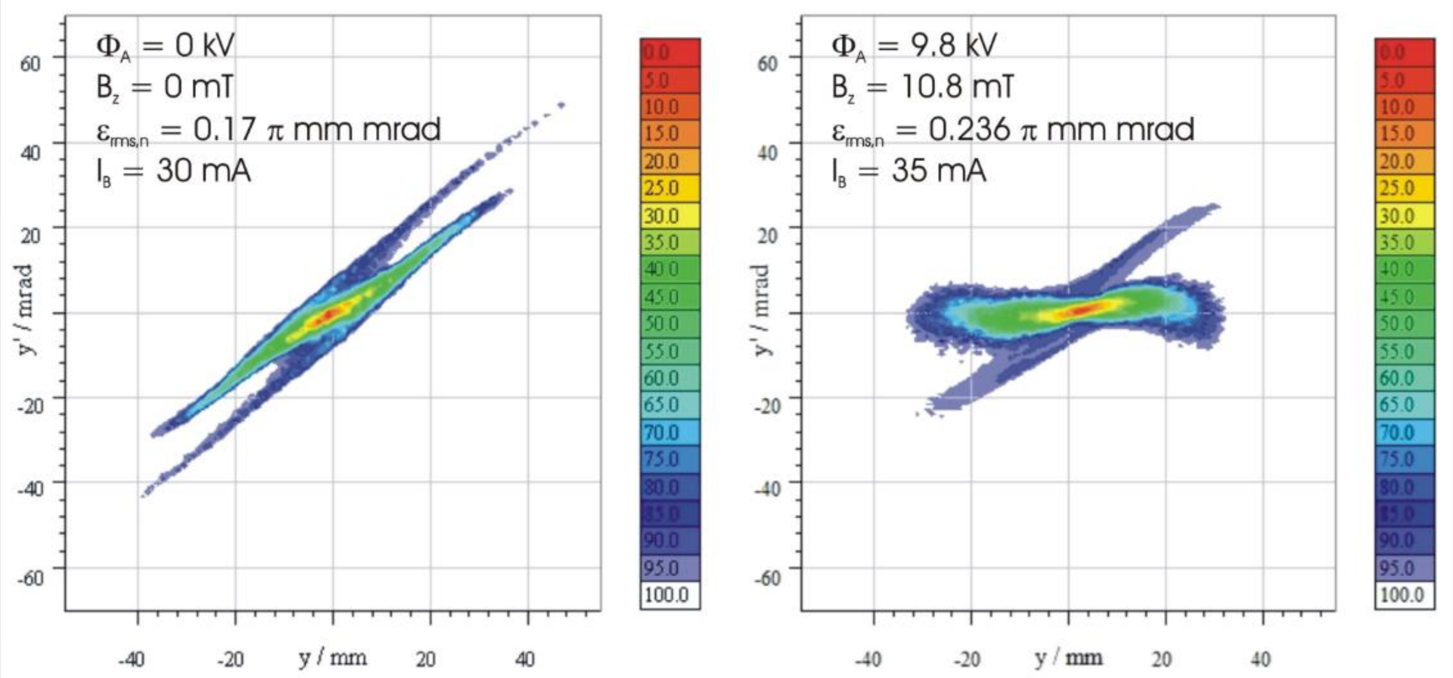


- r/l: 0.085/0.34 = 0.25
- $\phi_{A,max} \approx$ 50kV
- $B_{max} \approx$ 160mT
- $r_{plasma} \approx$ 5cm

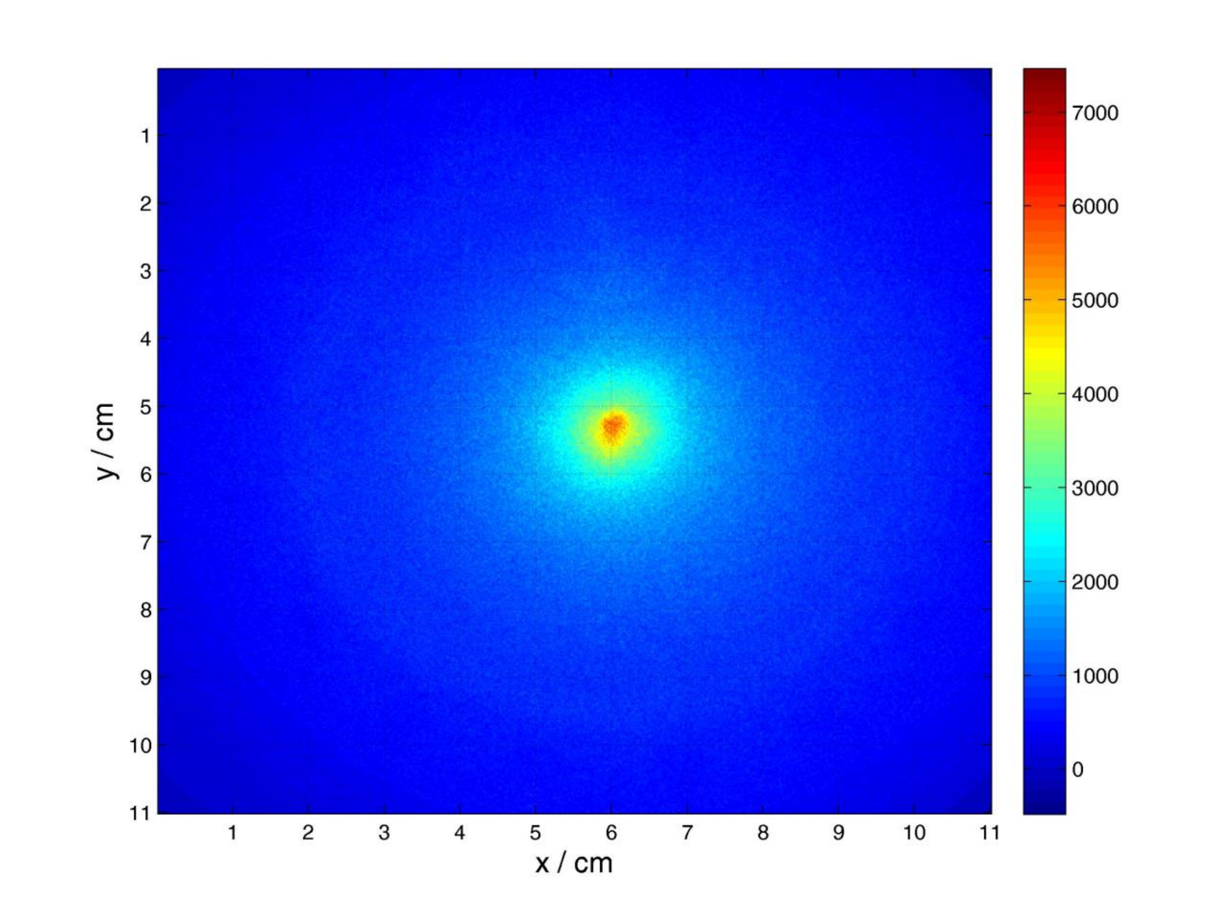
- Radial segmentation direction - potential
- Focussing of intense heavy ion beams in accelerators proofed (130keV, 35mA, Ar^{1+})
- Asymmetric confinement

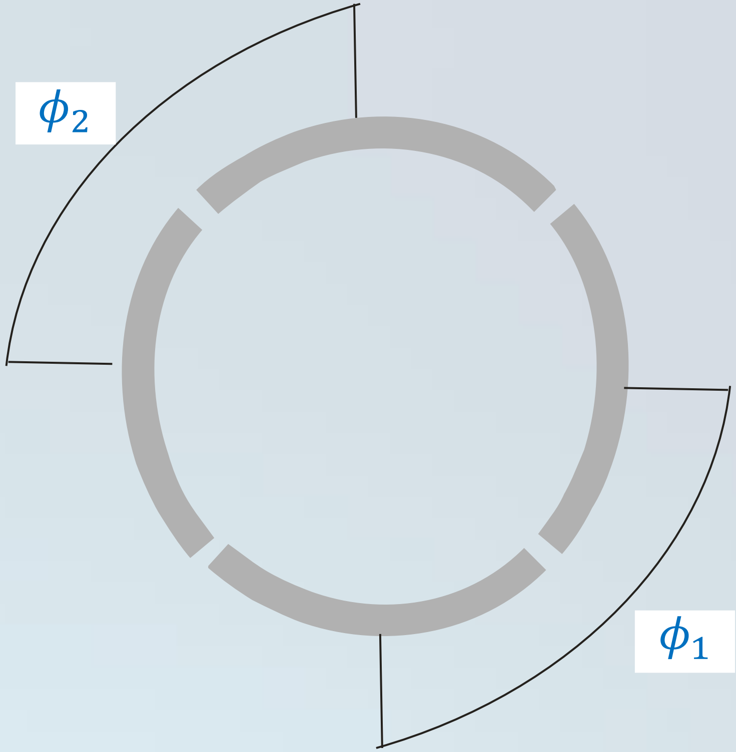
Hero – Segmented Gabor Lens

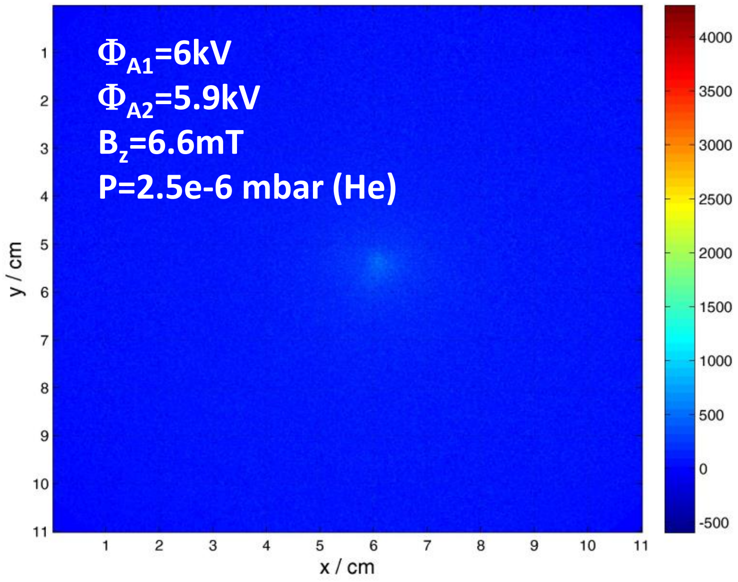
Focussing an ion beam with Gabor Lens – Emittance growing factor 1.38

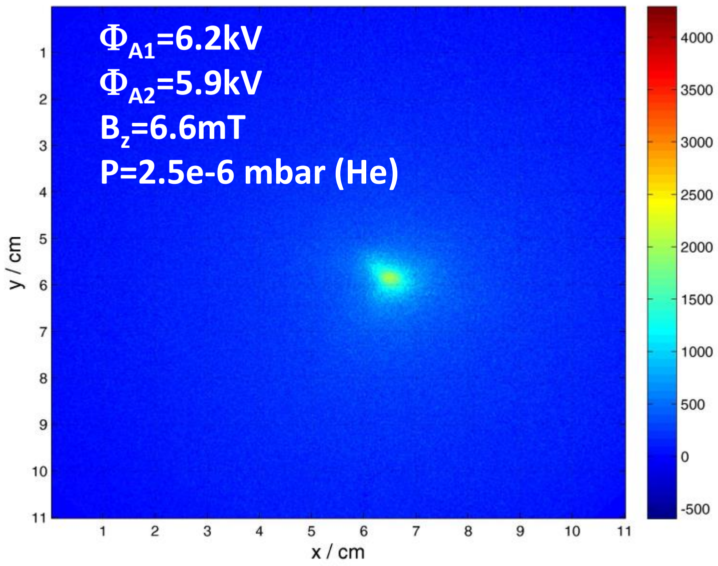


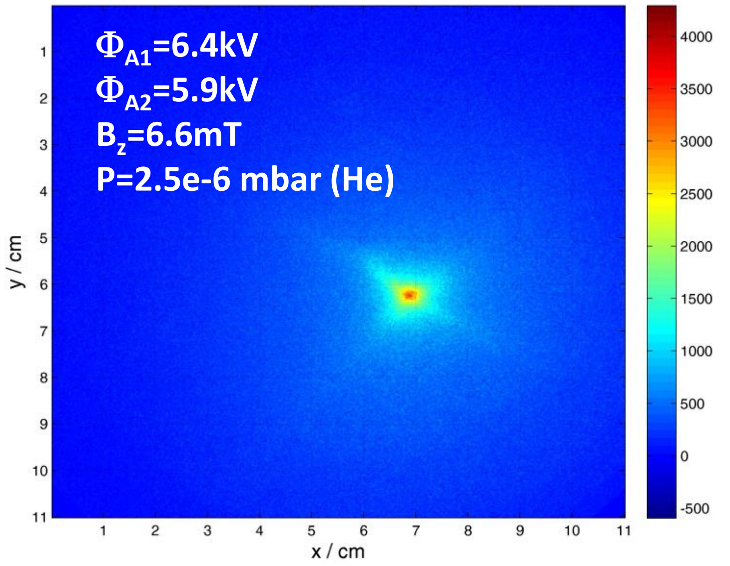
Asymmetric Confinement

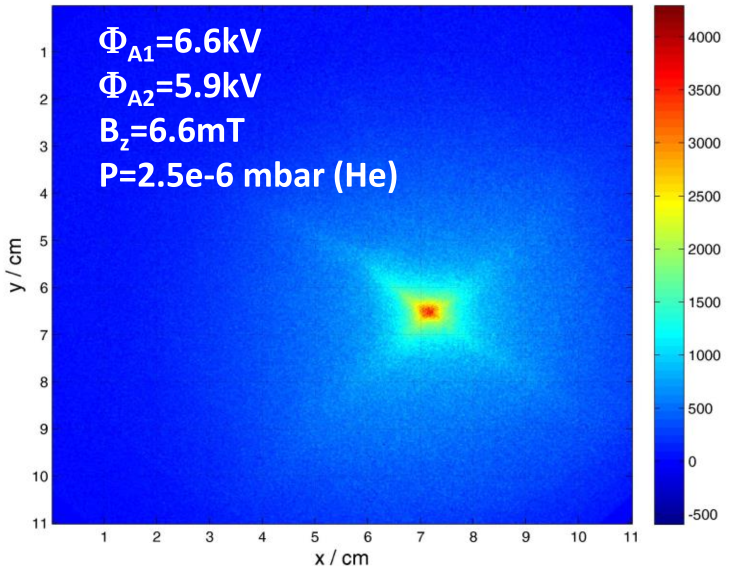


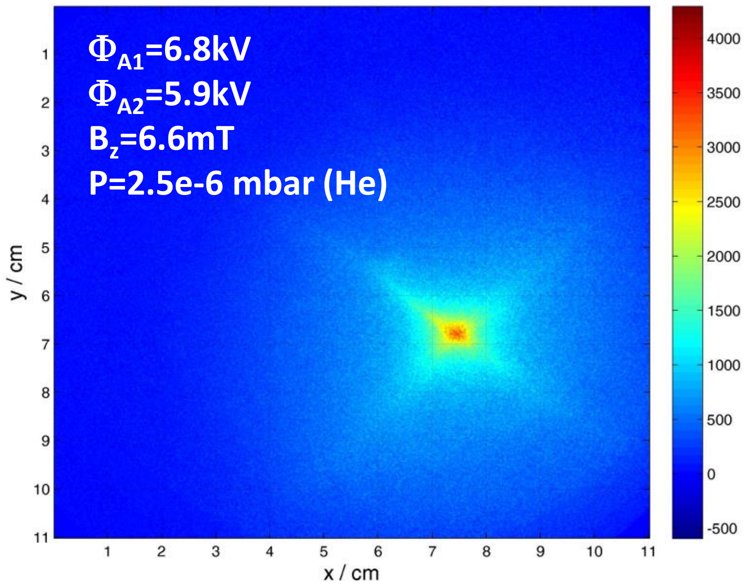


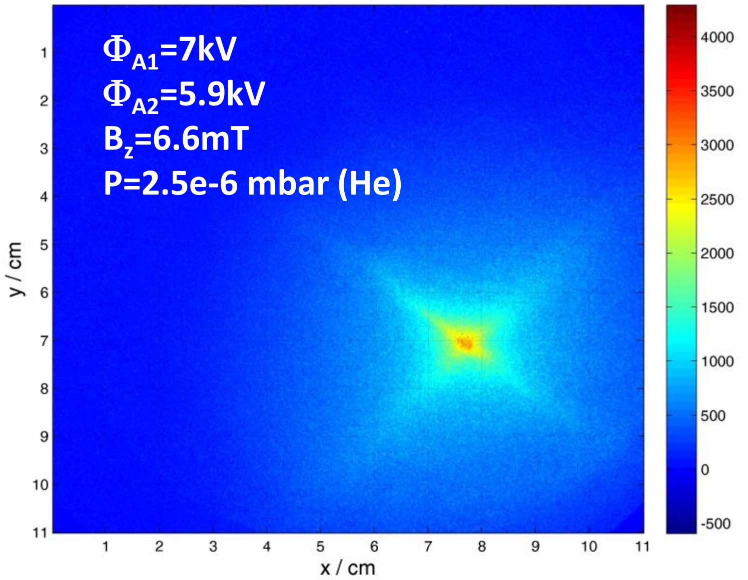

Φ_{A1}=6kV
Φ_{A2}=5.9kV
B_z=6.6mT
P=2.5e-6 mbar (He)
y / cm
x / cm


Φ_{A1}=6.2kV
Φ_{A2}=5.9kV
B_z=6.6mT
P=2.5e-6 mbar (He)
y / cm
x / cm

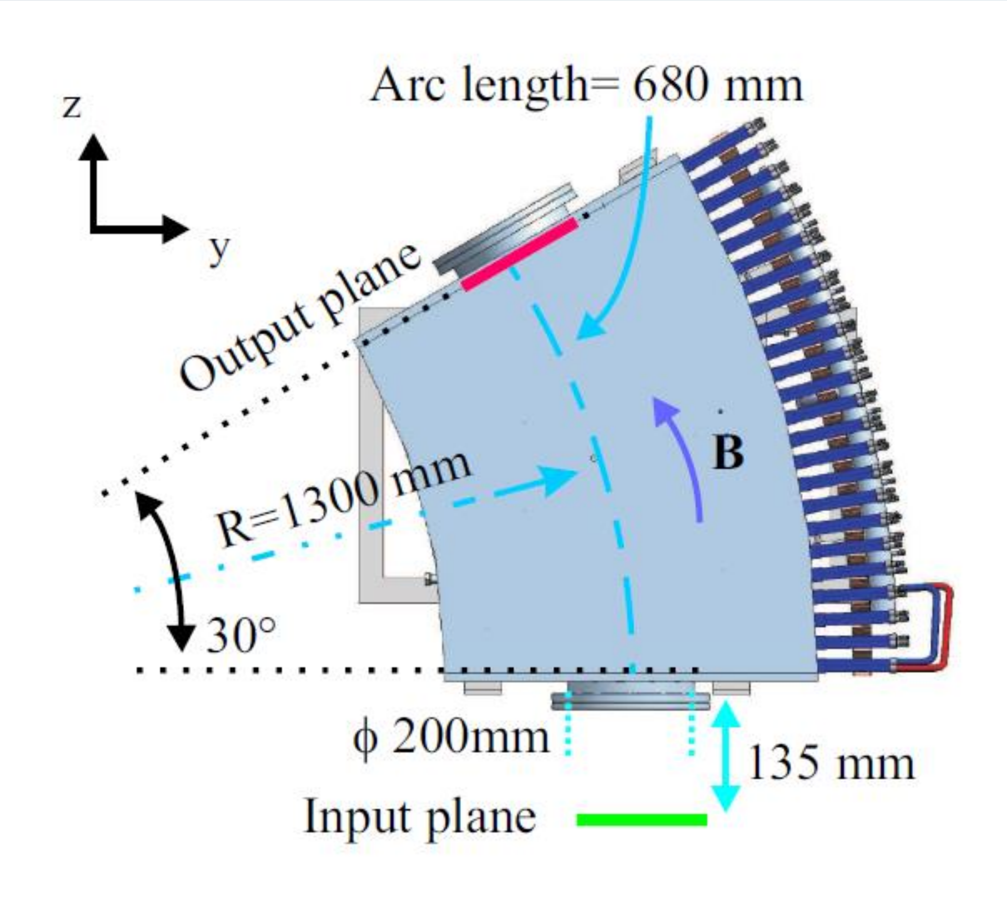

Φ_{A1}=6.4kV
Φ_{A2}=5.9kV
B_z=6.6mT
P=2.5e-6 mbar (He)
y / cm
x / cm

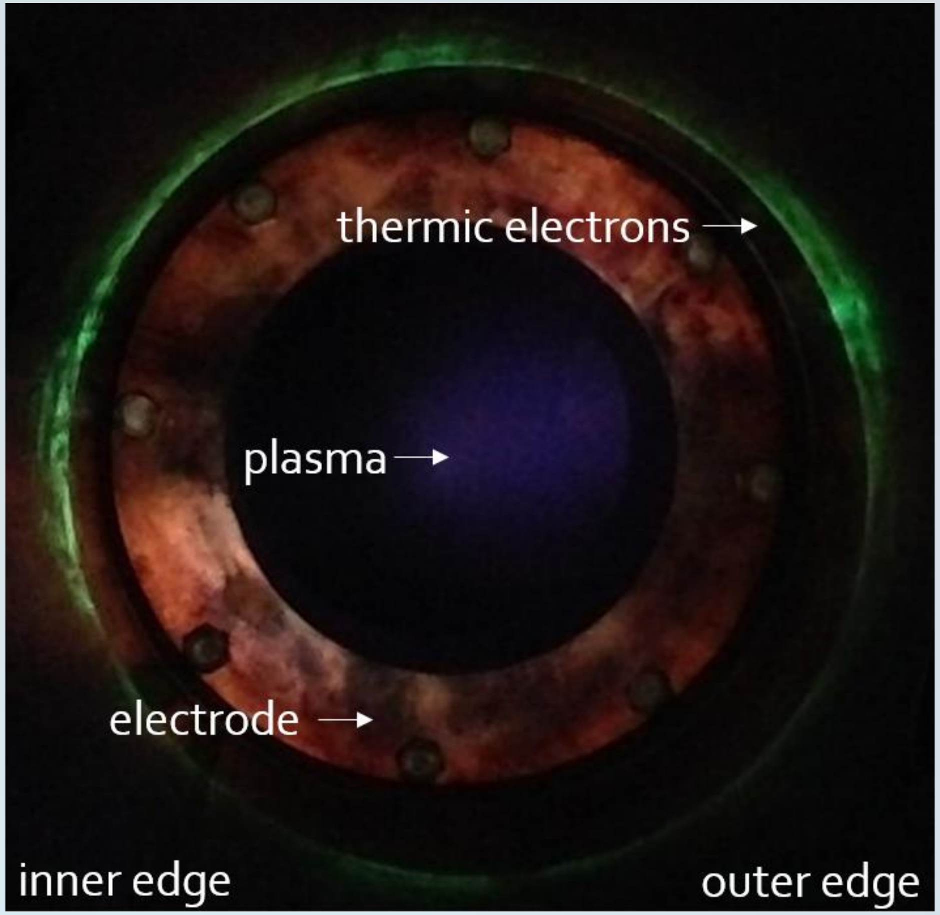

Φ_{A1}=6.6kV
Φ_{A2}=5.9kV
B_z=6.6mT
P=2.5e-6 mbar (He)
y / cm
x / cm


Φ_{A1}=6.8kV
Φ_{A2}=5.9kV
B_z=6.6mT
P=2.5e-6 mbar (He)
y / cm
x / cm


Φ_{A1}=7kV
Φ_{A2}=5.9kV
B_z=6.6mT
P=2.5e-6 mbar (He)
y / cm
x / cm

Asymmetric Gabor Lens





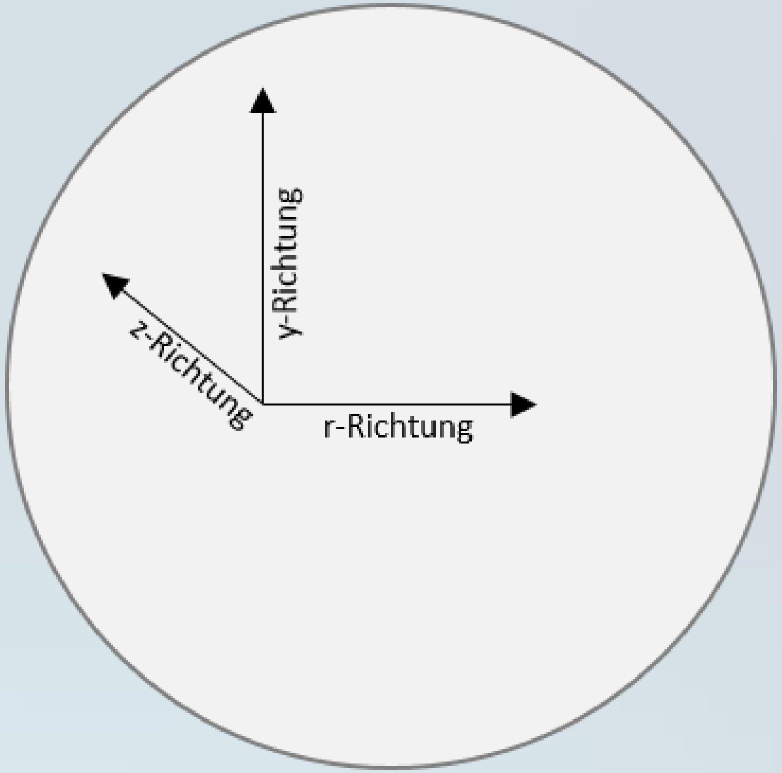
Asymmetric Gabor Lens

Parameters:

- r/l ratio: 0.147
- z-direction:

  680 mm - 2·40 mm = 600 mm
- y-direction:

  max ≈ 105 mm

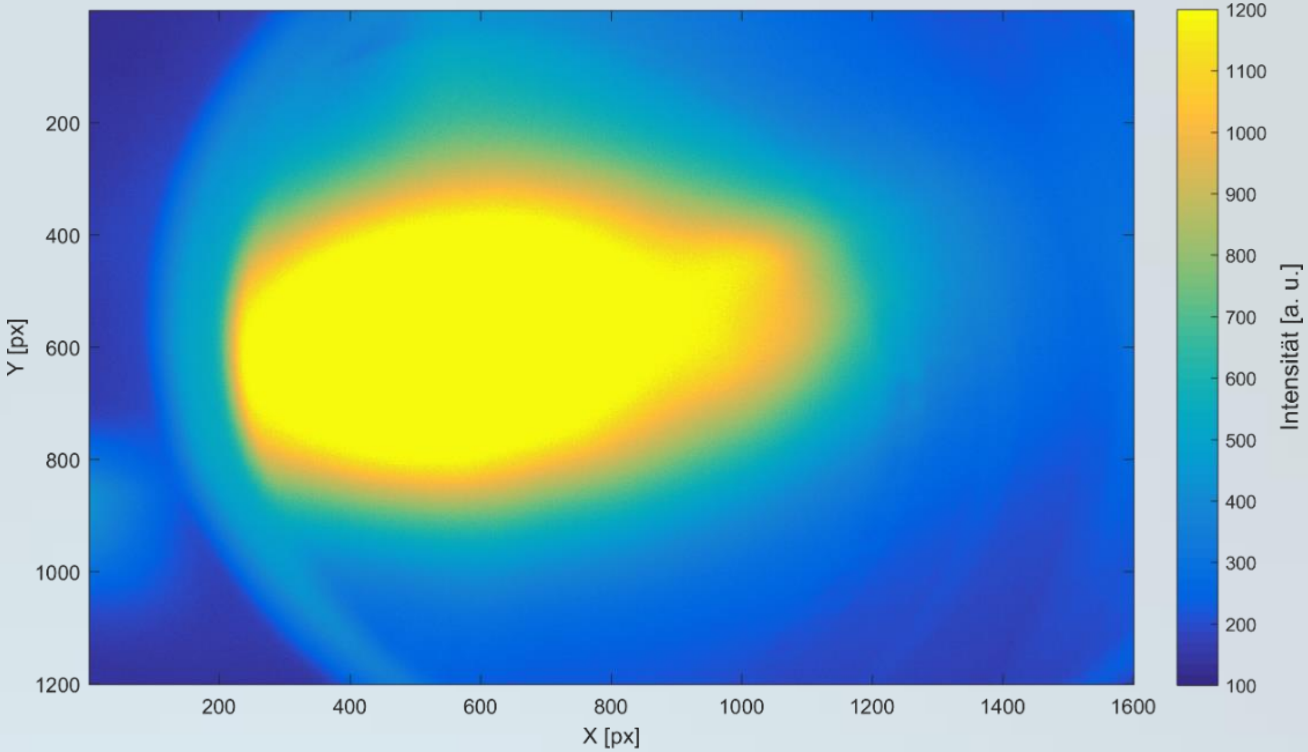


Asymmetric Gabor Lens

- Trapping electrons in an asymmetric potential and magnetic field
- Light density distribution is more intensive towards the inner edge of the beam tube

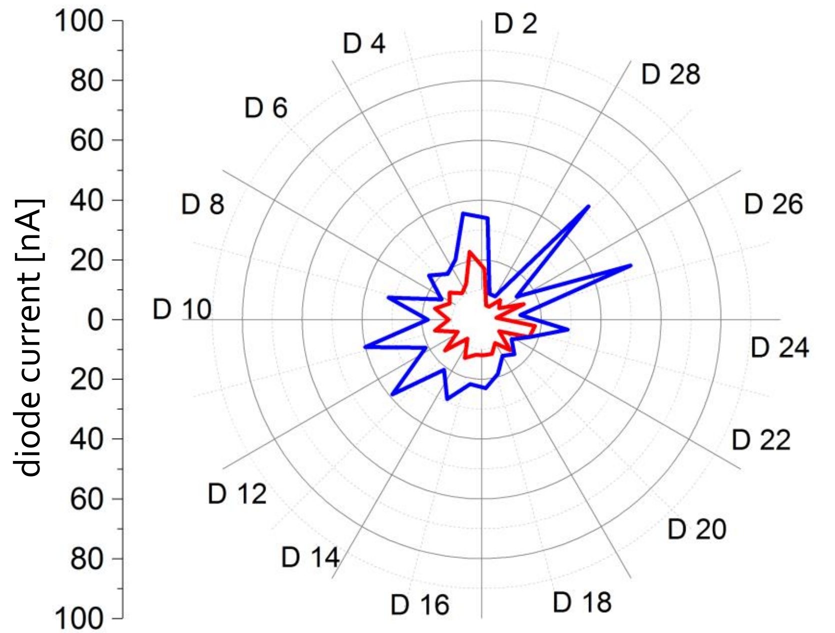
➢ Electron density is shifted to the higher magnetic field

➢ Non-neutral plasma is confined

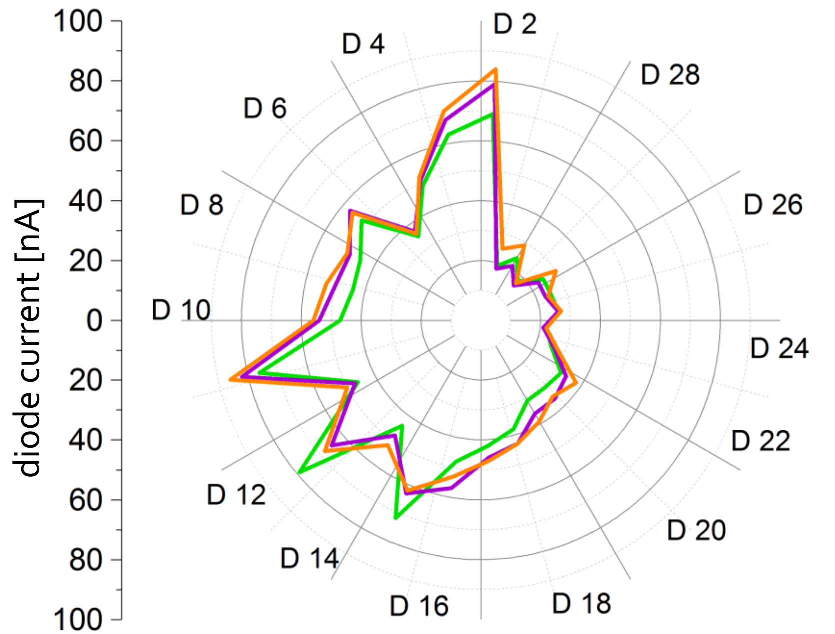


Asymmetric Gabor Lens

Example of insitu diagnostics (diode ring)



0.1 mA, 0.2 mA



0.5 mA, 0.6 mA, 0.7 mA

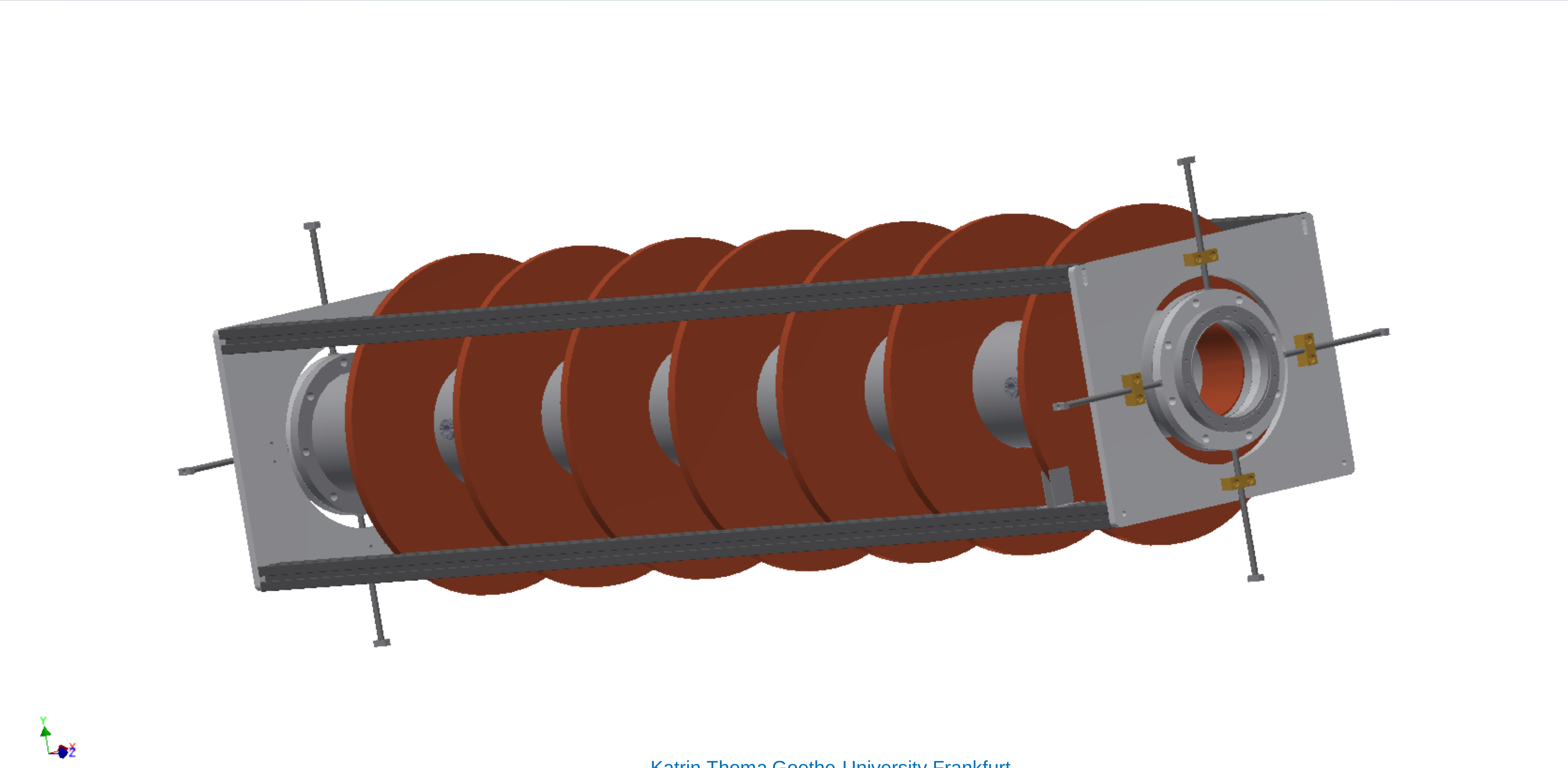
magnetic field constant, pressure constant, potential varied

Previous Research at NNP Group

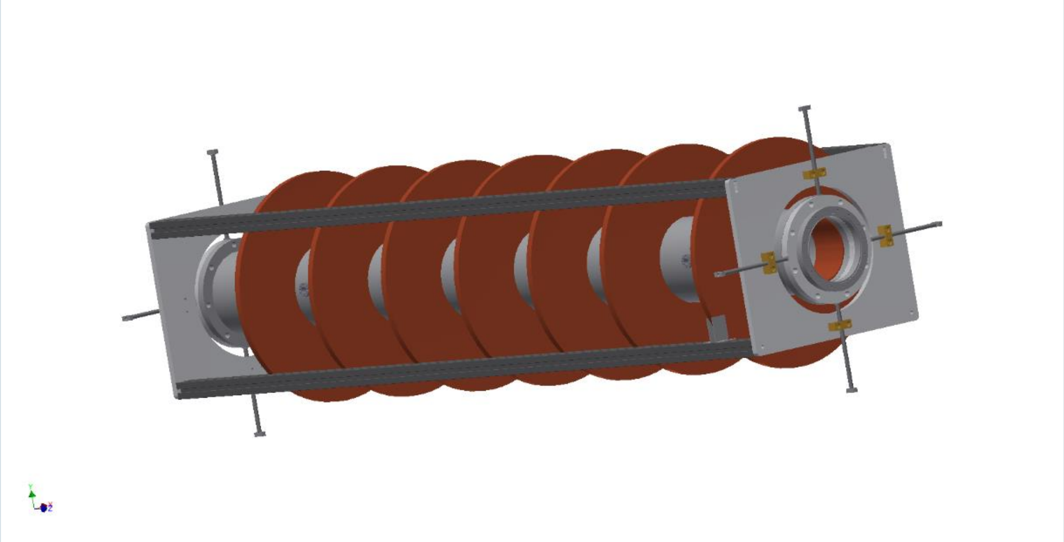
Main research topics:

- Determine plasma parameters, the losses, density and intensity distribution, experiments with beam
- Unsymmetric confinement, variation of e-cloud spatial position
- Long confinement times, studying r/l ratio of the column

New Lens under Construction GL2000



New Lens under Construction GL2000

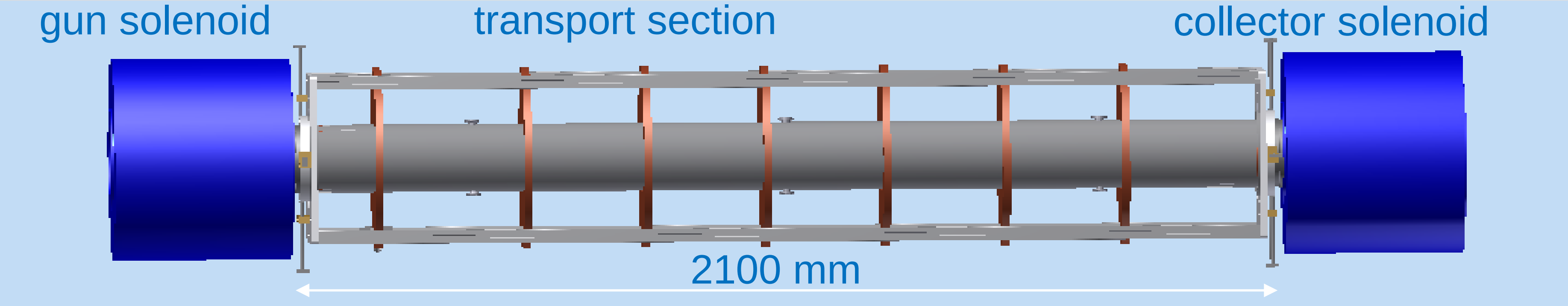


- r/l ratio of: 0.025
- Consists of 31 coils (pancakes)
- 2 m Anode longitudinal confinement
- 50 mm radial confinement
- Up to 30 kV Potential
- Performance will be evaluated by longitudinal electron pencil beam

Ambitions with GL2000

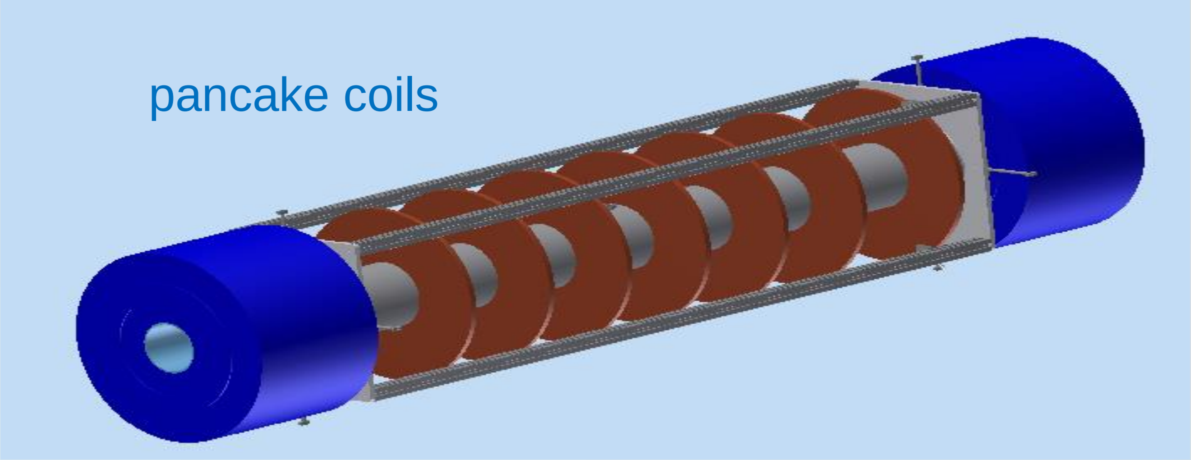
- Confinement of the largest Electron Column
- Stable confinement
- Plasma diagnostic, determining plasma parameters
- Pencil Beam experiments – determining focussing quality
- Beam bunch experiments with high intensity ion beams for emittance and space-charge dominated beams
- Studying interactions between cloud and ions – guiding the beam through the electron cloud without losses

Electron gun commissioning at IAP



Magnetic field

- GL2000 serves also as test bench for rf-modulated electron gun developed within ARIES WP16



Focussing an Ion Beam with GL2000

- Transit time of the beam through the GL2000:

$$\bar{v} = \frac{\Delta\bar{l}}{\Delta t}; \Delta t = \frac{\Delta\bar{l}}{\bar{v}} \approx 6{,}67 \cdot 10^{-9} s$$

with l $= 2m; v = c$

- Plasma frequency of NNP inside the lens:

$$\omega_{PE} = 2\pi f = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = 564{,}15\text{MHz} \Rightarrow \text{T} = 1{,}7 \cdot 10^{-9} s$$

with $n_e = 1 \cdot 10^{14} m^{-3}$

Focussing an Ion Beam with GL2000

- Transit time of the ion beam should be in maximum equal to the Non-neutral plasma frequency
- Bunch train frequency should be below plasma frequency

➢ Focussing space-charge and emittance dominated beams is possible

Conclusion

- Trapping electrons deliberatly by Gabor Lenses
  - Investigating knowledge about the Non-neutral plasma state
- Studying interactions between the cloud and the ions
  - Focal strength
  - Investigate diagnostics
  - Charge exchange/recombination
- Focussing space-charge and emittance dominated beams
  - Improvement of imaging properties (pencil beam experiments)
  - Reduction of ion beam losses
  - Reduction of emittance growth
  - Asymmetric guiding
- Building GL2000 for long and steady electron clouds

Thank you for your attention